



National Physical Laboratory

# **Photon Doses in NPL's Radionuclide Standard Neutron Fields**

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- In the real world a neutron field cannot exist in isolation.
- Always accompanied by associated photon field.
  - Neutron source
  - Inelastic neutron scattering reactions
  - Radiative capture reactions

## “Mixed Field”

- Instruments are often sensitive to both photons and neutrons
- Modern instruments capable of measuring photon and neutron dose.

To type-test and calibrate instruments NPL must know the photon dose of its standard neutron fields

# Standard Neutron Fields

- Most important are NPL's standard radionuclide neutron sources
- ISO 8529-1 details typical photon dose fraction  
Individual source is unique & must be individually measured

- Radionuclide Neutron Sources Measured

- Am-Be            15 Ci
- Am-B            15 Ci
- Am-F            1 Ci
- Am-Li           5 Ci
- Cf-252           1.5 mg (t~22 yr)
- D<sub>2</sub>O Moderated Cf-252    1.5 mg (t~22 yr)

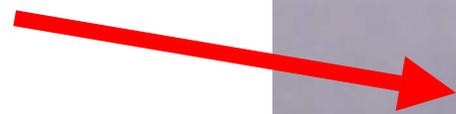
The photon dose  
from neutron  
interactions is small

- The most appropriate instruments are Halogen Quenched Energy Compensated Geiger Muller Counters.
  - Very low-fast neutron response
  - Useful photon dose response between 0.03 and 6 MeV
  - Simple and reliable
- MX164 (Perspex)
- MX164 (PTFE)
- ZP1000
- MX163 (PTFE)

PTFE reduces neutron response by eliminating hydrogen

# Instrumentation

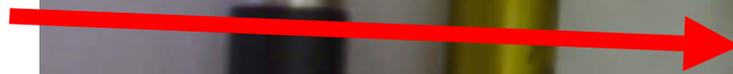
ZP1000



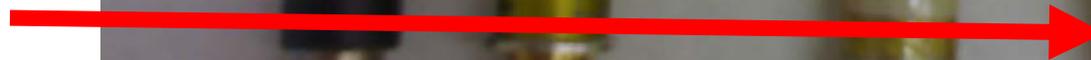
MX163



MX164 (Perspex)



MX164 (PTFE)

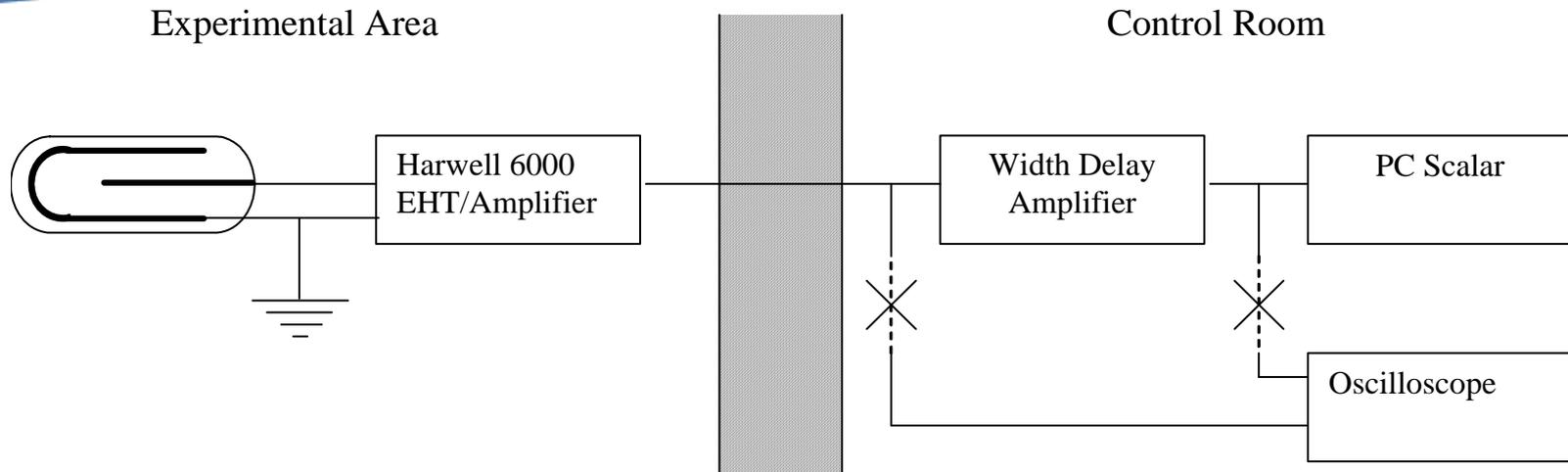


# Previous Measurements

- Previous measurement showed an unacceptable variation and did not appear to be repeatable.
- Maximum deviation of 75% from mean



# Electronic Set Up Arrangement



- Mounted perpendicular to source
- The dead time was imposed on the system by the width delay amplifier

• MX164            60  $\mu$ s

• ZP1000           30  $\mu$ s

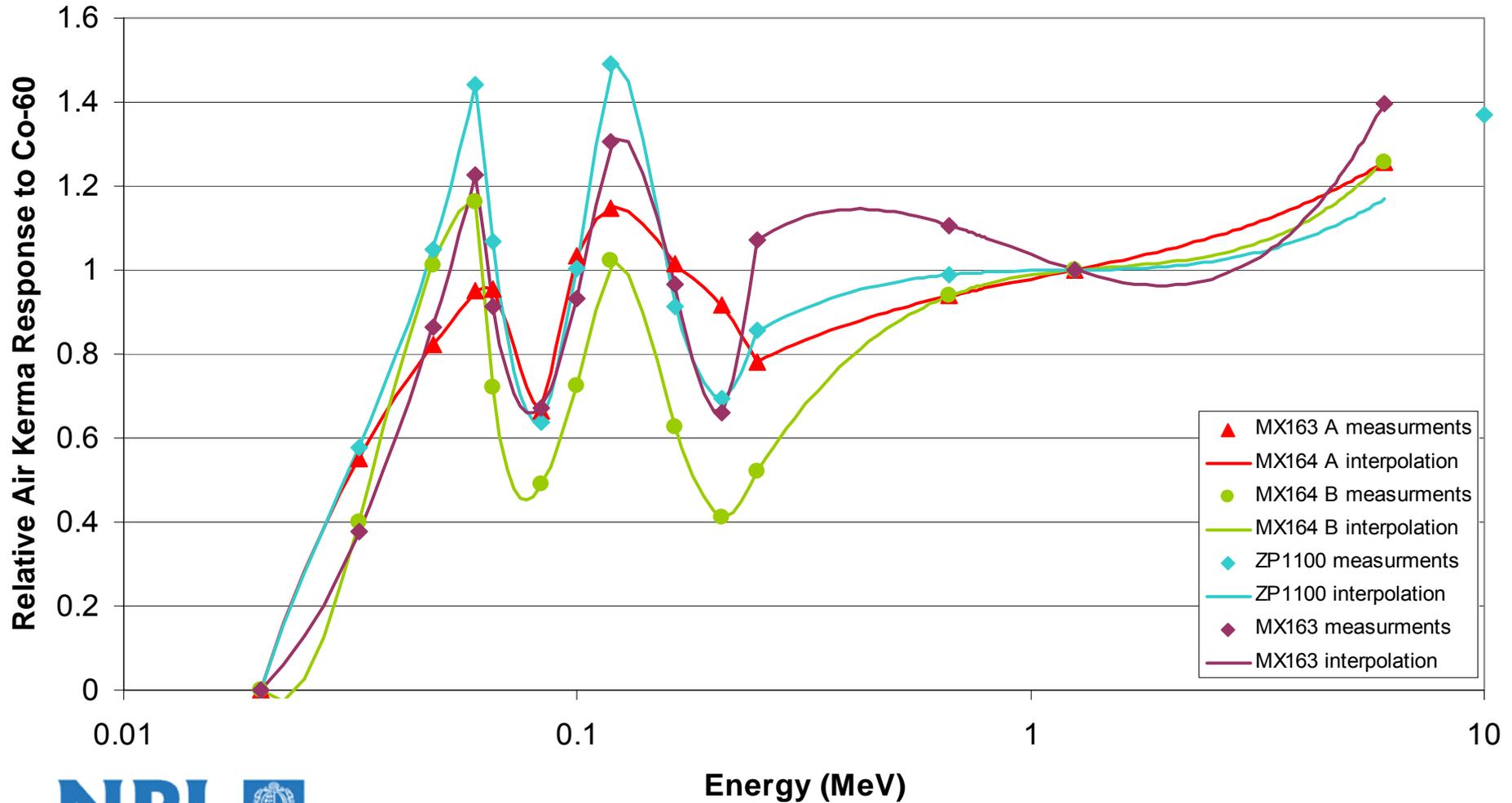
• MX163            30  $\mu$ s

# Photon Response Calibration

- Air Kerma response of Geiger Muller detectors calibrated using;
  - NPL's standard photon fields
    - Am-241, Cs-137, Co-60
    - Medium energy X-ray qualities
  - 6-MeV calibrations of detector type at Hinkley Point
- Where possible kept geometry and dose rates similar to expected mixed field measurements.
- 4-point cubic Lagrangian Interpolation creates smooth response between 0.02 and 6 MeV
- Energy response is not as flat as manufacture specification
  - Varies 60% between 0.06 and 1.2 MeV

# Photon Response of Geiger Detectors

## Detector Response



# Neutron source photon spectra

- Source photon spectra were estimated using ENSDF database and literature study of spectroscopic measurements.
- Corrected for attenuation due to source capsule, lead filter & air.
- Am based sources are dominated by 60-keV gamma ray
- Some higher energy components in lead filtered sources
  - Lead filtered Am-Be      large 4.45 MeV  ${}^9\text{Be}(\alpha,n)$  component
  - Lead filtered Am-Li      Dominated by 376-keV Gamma ray from  ${}^{241}\text{Am}$  decay
  - Californium      Complex and continuous  
Data taken from ICRU26  
22 yr old source complicated spectrum
  - MCNP used to calculate capture components in  $\text{D}_2\text{O}$  moderated Cf-252 spectrum.

# Photon response Corrections

- Correction of detector photon response

- Photon emission of each source was theoretically estimated
- Spectrum corrected for source and air attenuation
- Photon air kerma spectrum folded into detector response

- Air kerma measurements converted into protection quantities using ICRP74

Hp(10)  
H\*(10)

Source	Detector				Estimated Uncertainty
	MX164A	MX16B	ZP1100	MX163	
Am-Be	0.95	1.16	1.43	1.22	3%
Am-BE(Pb)	1.07	1.04	1.05	1.14	10%
Am-Li	0.94	1.15	1.43	1.21	3%
Am-Li(Pb)	0.89	0.79	0.95	1.11	3%
Am-B	0.94	1.16	1.43	1.22	3%
Am-F	0.94	1.16	1.43	1.22	3%
Cf-252	0.97	0.94	0.99	1.06	3%
D <sub>2</sub> O mod Cf-252	1.01	1.00	1.01	1.03	3%

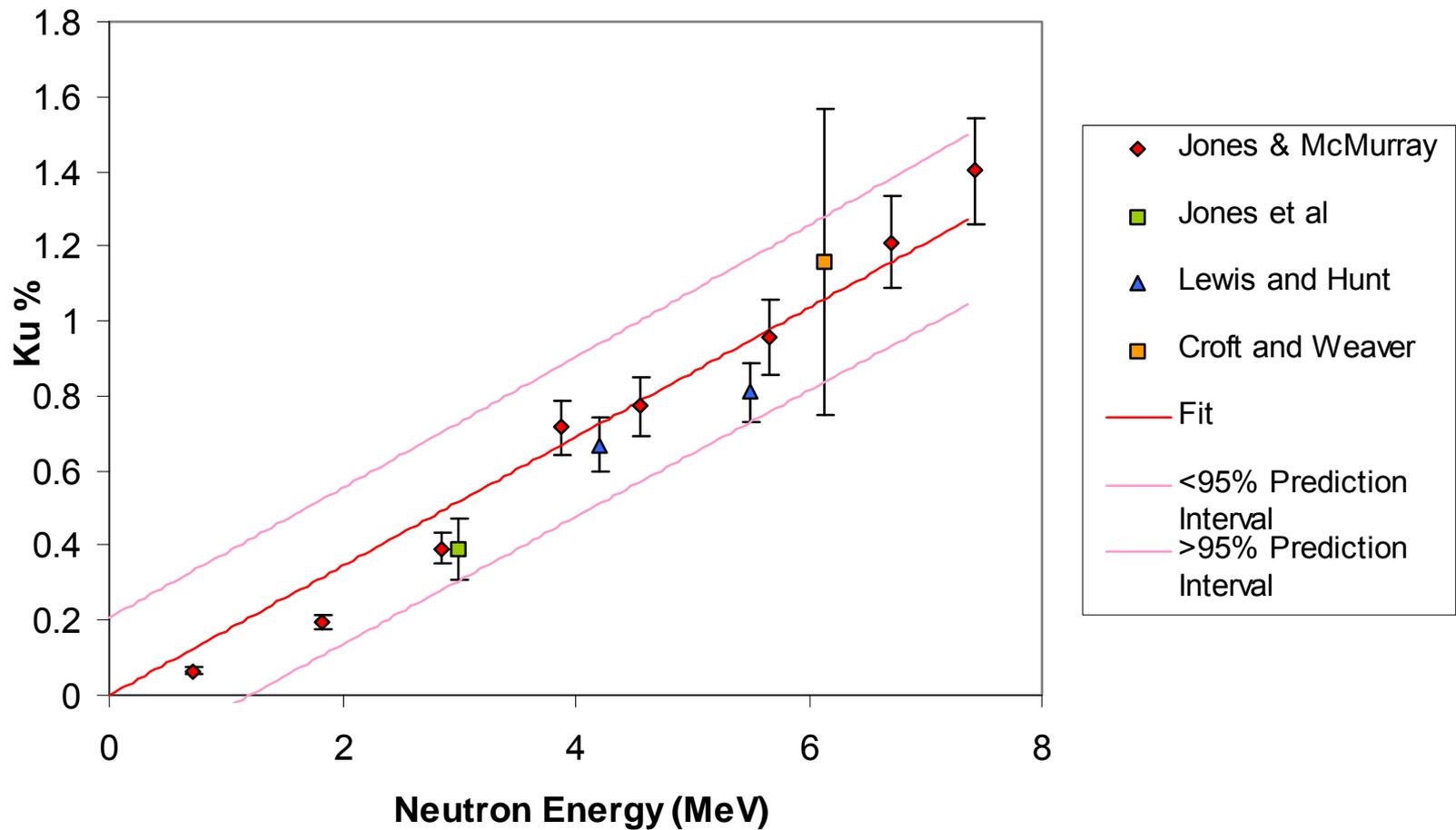
- Using Historic data the neutron sensitivity was estimated.  
Typically measured by  $k_u$

$$k_u = \frac{\text{Neutron response per unit neutron absorbed dose}}{\text{Photon response per unit photon absorbed dose}}$$

- Indicated that fast neutron response is approximately linear with energy.
- Approximate  $k_u$  for each source and detector was calculated
- Shown to be negligible over neutron energies of interest

# Neutron Response MX164

MX164 A & B

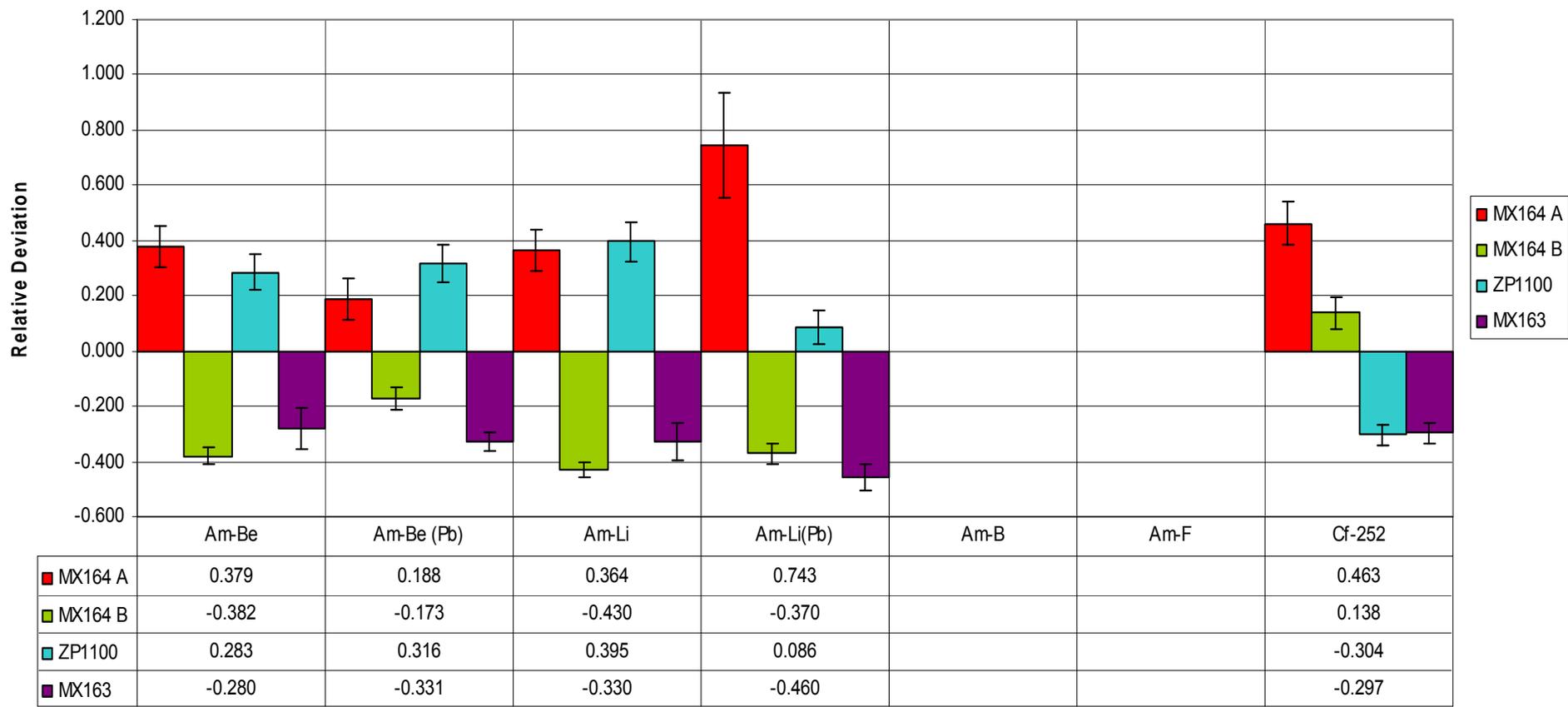


# Photon Field Measurements

- The air kerma rate free in air at 75 cm from each source were measured with the four detectors perpendicular to field.
  - Corrected for dead time (less than 1%)
  - Corrected for neutron sensitivity
  - Corrected for photon sensitivity
- Weighted mean of four measurements used to calculate air kerma rate.
- Total uncertainty typically between 1% and 3%
  - Uncertainty of Am-Be (Pb) was 5% due to poorly know photon response at 4.45 MeV.

# Variation in Measurements

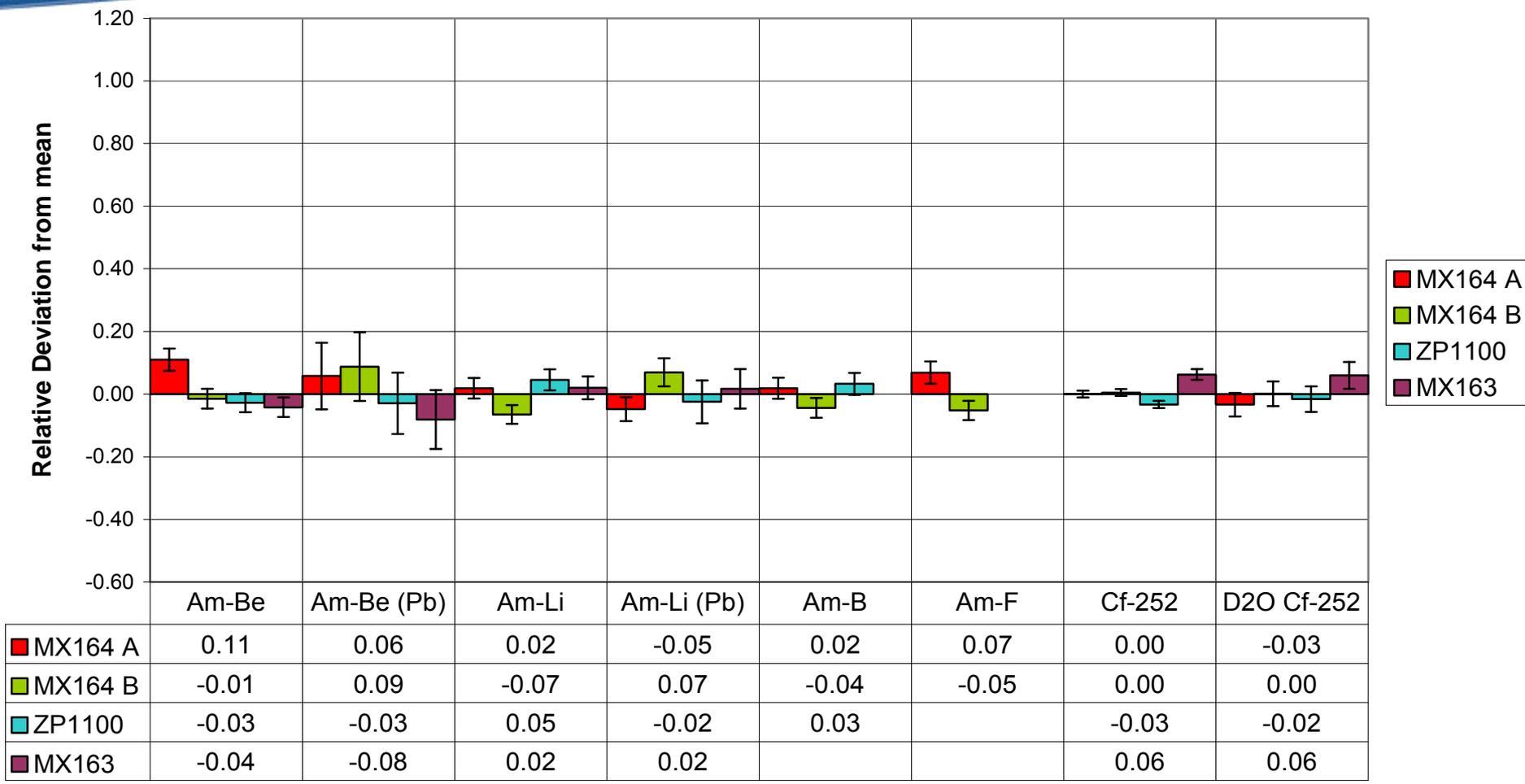
Fluctuation in 2003 measurments



Source

# Variation in Current Measurements

Variation in Geiger-Muller Measurements of Photon Air Kerma



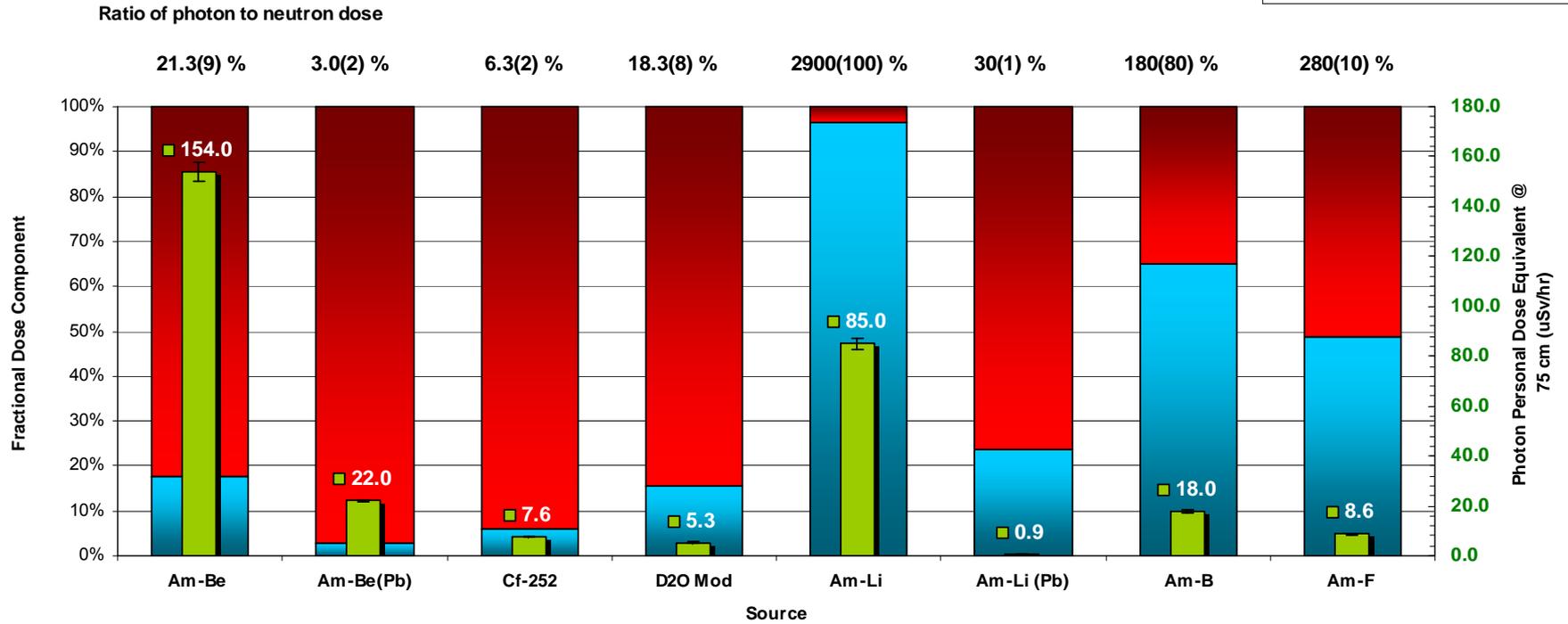
Source



# Results

Personal Equivalent photon Dose from Neutron Sources

■ Neutron Dose %  
■ Photon Dose %  
■ Photon Dose microSv/h



•Neutron dose quantities are the free field quantities calculated from the source emission rate measured by the NPL manganese bath facility and corrected for anisotropy.



# Conclusion

- We have characterised and measured the photon fields in NPL's standard radionuclide neutron fields.
  - Characterisation of the photon field and detector response is more detailed than in previous measurements.
  - Typical uncertainties were 3%. (much improved)
  - Excellent agreement with other authors
- 
- NPL has expanded it's capability and can now accurately measure the response of instruments sensitive to both photons and neutrons.

- NPL can continue to expand its capability by;
  - Measurement of accelerator based neutron standards
  - New set of Geiger Muller counters, with improved energy response.

Any Questions?